SMITHS INDUSTRIES
Aerospace

75242

Display & Control Systems Malvern
255 Great Valley Parkway
Malvern, PA 19355

U.S. Department of Transportation Dockets
400 Seventh Street, S.W.
Room Plaza 401
Washington, DC 20590

Reference: Docket No. FAA-l 99-6 11 FAA-99-6411-24

Smiths Industries Aerospace, Display & Control Systems - Malvern is pleased to offer the enclosed response to the above referenced docket number.

Please contact John Wyler at (610) 296-5000, extension 600 with any questions or comments.

Thank you for your consideration.

Sincerely,

L. Vasko

Laura J. Vasko
Marketing

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Display & Control Systems - Malvern

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Response to the FAA Notice of Proposed Rulemaking (FAA Docket No. FAA-1999-64-11; Notice No. 99-18)

Proprietary Notice

20016 SFAR

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1 SMITHS BACKGROUND/INTRODUCTION

Smiths Industries welcomes the opportunity to submit comments to the FAA NPRM for Transport Airplane Fuel Tank System Review, Flammability Reduction and Maintenance and Inspection Requirements. Smiths Industries has been a supplier of aircraft fuel quantity systems for over 50 years. An overview of our fuel quantity experience is illustrated in Figure 1-1.

Smiths Industries comments to the NPRM arise from our perspective as an established supplier of fuel quantity systems and emphasize the technologies we are developing in response to demands for improved aircraft safety.

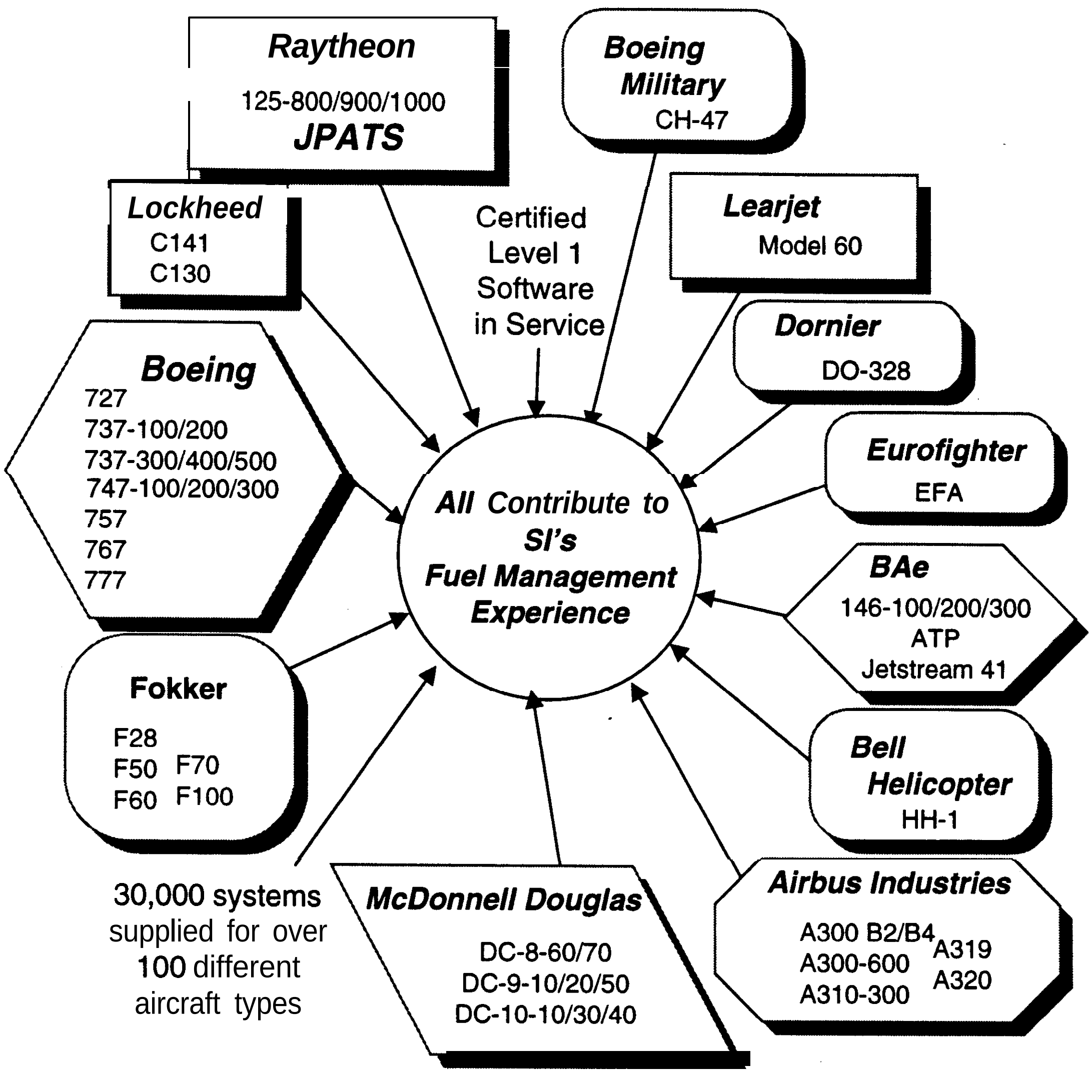

Figure 1-1 Smiths Industries Fuel Management Experience

2 Comments on "Background"

Smiths Industries acknowledges that the tragic TWA Flight 800 incident has been attributed to a center tank explosion and that this unfortunate incident represents the single biggest factor in industry's reassessment of fuel tank ignition risks.

2.1 Flammability characteristics

Smiths Industries acknowledges that the flammability characteristics of aviation fuels are being studied to assess possible changes to fuel composition or aircraft operational procedures.

The NPRM identifies hot surface ignition and autoignition as possible ignition sources. Although the mechanism for ignition is similar, the ASTM test methods for establishing autoignition and hot surface ignition temperatures are different, and hot surface ignition temperatures tend to be higher than autoignition temperatures for a given fuel. The NPRM states that "possible ignition sources that have been considered include autoignition" which is then contradicted by the following parenthetical sentence that defines autoignition as occurring "in the absence of an ignition source". Temperatures that equal or exceed the autoignition or hot surface ignition temperatures should be designated as possible ignition sources.

The intrinsic safety principles used by Smiths Industries for fuel quantity indicating system design always assume a flammable atmosphere is present in the tanks.

2.2 Existing regulations/certification methods

Smiths Industries is aware of the existing regulations cited.

2.3 Airplane maintenance manual

Smiths Industries is aware of the existing requirements for maintenance manuals and continued airworthiness.

2.4 Type Certificate amendments

Smiths Industries has obtained several STC's to allow installation of digital fuel gauging on older airplanes.

2.5 Maintenance and inspection program RQMTS

Smiths Industries is aware of the existing regulations cited.

2.6 NTSB – Reduced flammability exposure

Smiths Industries agrees with NTSB recommendation A-96-177 concerning the addition of temperature monitoring systems in fuel tanks located near heat sources.

The electrically non-intrusive B777 type fuel tank temperature probe illustrated in Figure 2-1 could have applications for monitoring in-tank temperatures and provide a warning if the fuel reaches a hazardous level.

In DC fuel quantity systems, fuel temperature can be inferred from characterized diodes that are an inherent part of DC fuel probes.

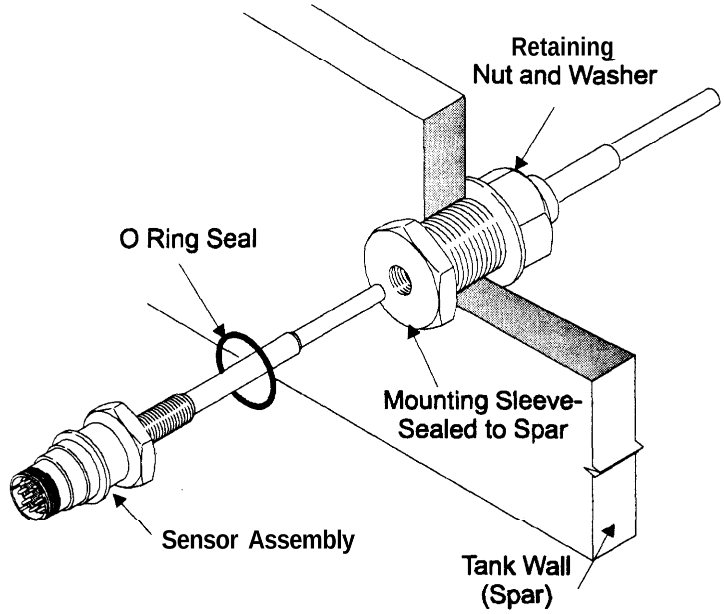

Figure 2-1 Non-intrusive Fuel Tank Temperature Probe

2.7 NTSB – IGNITION SOURCE REDUCTION

Smiths Industries is actively developing ignition source reduction methods. We have developed a Transient Suppression Unit (TSU) for the B747 and B737 classic fleets and are developing an arc detection system for fuel pumps and valves. Details on both of these ignition source reduction technologies are discussed in later sections.

2.8 AGING AIRPLANE RELATED PHENOMENA

The post TWA 800 inspections have uncovered numerous instances of system deterioration that could contribute to development of ignition sources.

Conductive debris in fuel tanks is a cause for concern with capacitance probes where each of the concentric tubes acts as the electrode of a capacitor. Conductive debris bridging the gap between the probe electrodes or between an electrode and airframe ground, when combined with other system faults such as lightning induced currents or hot shorts on the FQIS wiring can lead to in-tank currents exceeding safe limits. This threat can be minimized by surrounding the active electrodes in an outer electrode that is bonded to airframe. Such a technique is currently used on some military aircraft with composite tanks for EMI hardening.

New gauging technologies may also be more immune or tolerant to the effects of aging aircraft.

The SI ultrasonic fuel gauging technology employed on the B777 overcomes the threat of debris. The single tube or stillwell of the ultrasonic fuel probe is bonded to airframe and the entire mechanical assembly is electrically inactive.

2.8.1 Summary of Smiths sulfide study

Approximately a year ago a US Air Force mechanic removed a fuel gauging probe from an aircraft and during checking its insulation resistance reported a spark. A similar incident was reported with a probe from a Tower Air aircraft (a contemporary of the Flight TWA800 aircraft) and is now under investigation by the National Transport Safety Board ("NTSB").

Since January 1999 an investigation at the University of Dayton Research Institute and Stanford Research Institute ("SRI") has been in progress with assistance from Boeing and B. F. Goodrich.

Reports of an experiment by Dr. Mike McKubre of SRI reported the production of a "white hot" spot, "smoke", "molten silver deposits" and black "sulphide" deposits with low voltages lower than those available in aircraft harnesses under fault conditions. The experiment involved the use of silver plated copper wire of the type used in aircraft wiring harnesses.

Based on the reported facts this experiment was replicated in the Smiths Industries, Cheltenham, UK site in an attempt to reproduce the reported effects and observe them in more detail.

Using initial 9 volt DC battery power and subsequently 28 volt DC power numerous replications of the reported experiment were performed and no "sparks", smoke or "molten silver deposits" were observed although other visual effects that could be mistaken for them were. The black deposits produced in the experiment were mixtures of silver and (predominantly) copper oxide by means of a simple electrochemical reaction.

The experiments were summarized in "Lab Sketch" document, serial number "LS.RPT.3633". The experimental work was documented (incorporating photomicrographs and video "stills") in "Lab Sketch" documents, serial numbers: "LS.RPT.3601", "LS.RPT.3616", "LS.RPT.3628" and "LS.RPT.3632". The hypotheses and equipment used was described in "Lab Sketch" documents, serial numbers "LS.RPT.3612" and "LS.RPT.3629" respectively.

In brief, the "sparks" were reflected highlights off bubbles, the "smoke" was water vapor and the "molten silver deposits" were also reflected highlights off bubbles or wet surfaces. Results of this investigation are documented in LS.RPT.3671.

Subsequently samples of deposits from an in-service probe have been obtained and are being subject to on-going chemical and physical investigation.

The fuel probe shown in Figure 2-2 was removed from a Belgium Airforce 748 by BAE SYSTEMS at the request of SI Basingstoke for the specific purpose of obtaining "black deposits". The deposits have been removed from the contacts and are currently being analyzed by Express Separations Ltd.

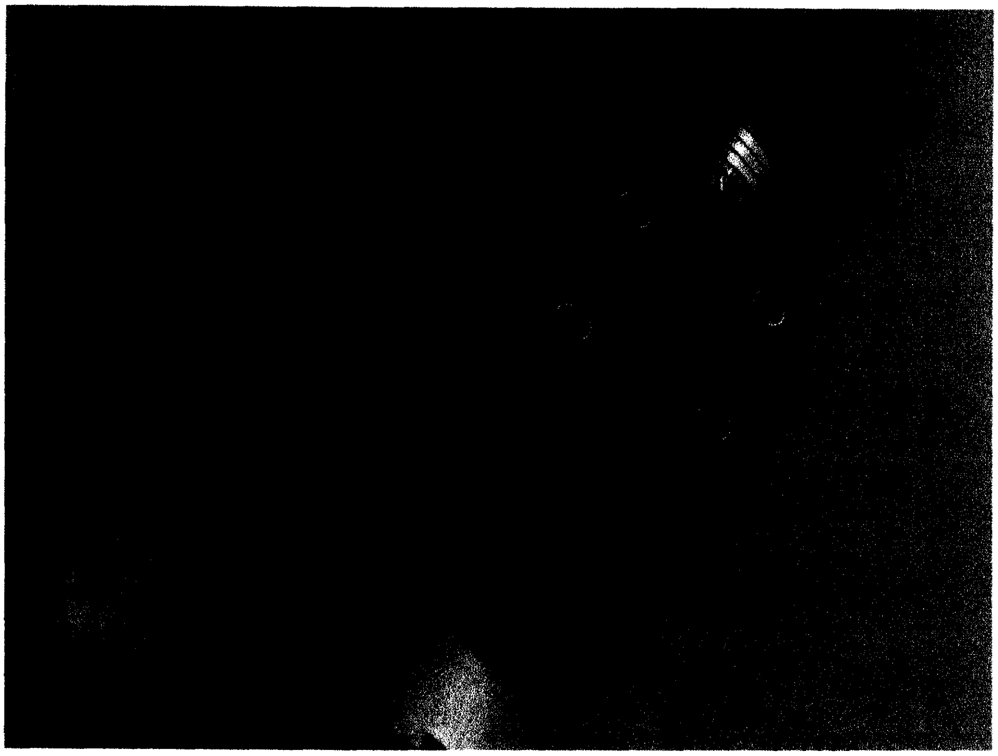

Figure 2-2 Fuel Probe with "Black Deposits"

2.9 UNFORESEEN FUEL TANK SYSTEM FAILURES

Condition Assessment/Inspection Programs (CA/IP) for older military aircraft and incident/accident investigations of military aircraft revealed many of the same aging problems and failures discussed in the NPRM for commercial transport airplanes.

An item that was overlooked is fuel leakage from tanks or components into areas where potential ignition sources exist.

2.10 REVIEW OF FUEL TANK MAINTENANCE PRACTICES

Smiths Industries questions the statement "Typical transport category airplane fuel tank systems are designed with redundancy and fault indication features such that single component failures do not result in any significant reduction in safety." Just the opposite is true, current designs are single thread systems. That is because there will be an explosive mixture in the tank on a regular basis, and there is likely to be debris in the tank so any single failure such as a hot short will compromise safety. The same is true for pump insulation failures.

2.11 LISTING OF DEFICIENCIES

Missing from this listing is fuel leakage into areas where ignition sources may exist. An example might be fuel leakage through the FQIS tank wall connectors onto an engine hot air bleed duct.

2.12 FUEL TANK FLAMMABILITY

Smiths Industries believes that the ARAC report referenced is flawed in its logic that arrived at a suggested exposure time to explosive conditions not to exceed 7% of fleet operating time. This recommendation was based on comparison of the incident rate for center tanks to that for wing tanks. An explosion takes two things; an explosive mixture and an ignition source. It is doubtful that highly explosive mixtures ever exist in wing tanks. Due to operating procedures, the wing tanks are seldom empty, and they are not located near any heat sources. While wing tank vapors may be explosive when taxiing on a hot runway for extended periods of time, they are never as explosive as those that often exist in empty center tanks. The most serious situation would be when the airplane lands on a hot runway with nearly empty wing tanks. However, taxi time at landing is usually short. At takeoff, even with long taxi the wing tanks will be nearly full with relatively cool fuel. So, to have comparable safety margins for center tanks as for wing tanks, the degree of explosiveness would also have to be equilibrated.

3 COMMENTS ON "DISCUSSION OF THE PROPOSAL"

3.1 PROPOSED SFAR

3.1.1 Safety Review

Prior to conducting a system safety review and analysis for each aircraft type, consideration should be given to conducting a detailed fuel tank inspection of several representative airplanes for each aircraft TC. The inspection should span both old and newer airplanes and include at least two operators and at least 10 airplanes. This should be a very aggressive inspection including removal and teardown of components and inspection of difficult to reach areas. The deficiencies and failures listed in this NRPM as well as the findings of the 747 fuel tank inspections by representatives from ATA, AEA, AAPA, et al, could provide a starting point for defining the nature of the inspections.

Based on findings of the inspections, i.e., chafed wiring, brittle or cracked insulation, evidence of arcing, missing or damaged flame arrestors, damaged conduits, FOD in the tank or pumps, degraded connectors, copper-sulfur deposits, etc., appropriate corrective action can be defined. Maintenance intervals can be based on findings on older versus newer airplanes (or less operating hours). Required design changes will become apparent.

As a precedent to this type of inspection, the United States Air Force conducted aggressive inspections of B-52 and KC-135 aircraft in the 1980s to establish the condition and required corrective action for continued safe operation of these aging aircraft. The Programs were referred to as Condition Assessment/Inspection Programs (CA/IP). The CA/IPs were conducted for many of the same concerns expressed in the NPRM, although the programs covered other aircraft systems (electrical, avionic, hydraulic, pneumatic, etc.) as well. The CA/IP findings resulted in numerous fuel system corrective actions to enhance safety, including maintenance actions/intervals and design improvements. The B-52 and KC-135 CA/IPs were performed by Boeing -Wichita under the direction of the USAF Oklahoma City Air Logistics Center (OCALC). Perhaps OCALC would be willing to share the CA/IP approach with the FAA.

3.1.2 Maintenance instructions

See comments above for Safety Review.

3.1.3 Possible Airworthiness Directives

Smiths Industries recognizes that several Airworthiness Directives may result from this activity.

3.1.4 Applicability of the proposed SFAR

Unless costs are prohibitive for the smaller aircraft, the proposed SFAR should not be limited to aircraft with a certified passenger capacity of 30 or more and payload capacity of 7500 pounds or more. It is safe to say that the fuel safety concerns expressed in this NPRM apply to the complete range of passenger capacity aircraft and it is difficult to rationalize why the safety level for 29 passengers should be less than for 30 passengers.

3.1.5 Supplemental Type Certificates (STC)

Smiths Industries holds six STCs for replacement fuel quantity indicating systems on the B727, B737, DC-8, DC-9 and DC-10 aircraft. A design objective of our replacement system is to supply a system compatible with the existing tank probe configuration(s). Accordingly, the replacement equipment supplied under these STC's is limited to fuel quantity indicators, repeaters and other ancillary devices such as Fuel Summation Units. No modifications to the in tank probes or compensator or harnesses is required.

In our case as STC holder we are not responsible for the wire routing and harness configuration of the existing system, and as such should not be responsible for assessing whether or not the harness routing is acceptable from an overall system safety perspective. We are surely responsible for assessing the safety of our replacement indicators, and in those cases where a replacement connector or the re-pinning of existing connectors is required we will assess the safety impact of these changes.

It is our opinion that as holder of an STC for a replacement fuel quantity indicating system that is limited to an instrumentation change only, we are not liable nor can we be held responsible for the original fuel tank design and harness routing. Please note that Smiths Industries has introduced a new Transient Suppression Unit that mitigates the effects of inappropriate harness routing.

3.1.6 Compliance

As stated in the NPRM, the compliance period of 12 months is for completion of a safety review and development of required maintenance and inspection instructions. It is Smiths Industries position that maintenance and inspection instructions alone are insufficient. Additional measures should be taken to protect fuel tanks from potential ignition sources such as HIRF, lightning and cable hot shorts. Much of our effort since the TWA 800 incident has been focused on the development of such measures. This effort has culminated in the Transient Suppression Unit (TSU). The TSU eliminates the need to inspect harnesses, probe terminations etc. The TSU itself would be subject to periodic (25,000 hours) inspections.

Smiths Industries believes that 12 months is an insufficient time period in which to conduct a thorough safety assessment of the replacement fuel quantity indicating systems for which we hold an STC. Although a substantial portion of the analyses and testing that demonstrate that those systems for which we currently hold an STC (as well as almost every other aircraft affected by the NPRM) will comply with the SFAR when fitted with our retrofit system and a Transient Suppression Unit are complete, our effort to date has focused on the B737 and B747 Classic fleets. Smiths Industries feels that twenty four (24) months will be sufficient time for us to extend the current documentation suite to those aircraft types for which we hold an STC.

As stated earlier, our STC's do not impact the configuration of the fuel tanks nor any equipment internal to the fuel tanks or the routing of the out-tank FQIS harnesses. Therefore, it is our position that the original aircraft manufacturer should be responsible for these portions of the assessment.

3.1.6.1 Non Fuel System STC's

Smiths Industries acknowledges that aircraft modifications accomplished under non-fuel system STC's may include wire harness installations that run adjacent to fuel quantity harnesses. Each of these installations should be reviewed to identify any occurrences of co-located harnesses. The proposed rule suggests that the fuel system STC holder should be responsible for this review. It is Smiths Industries position that the holder of the non-fuel system STC is the party best suited for conducting such a review. It is not clear how we as a holder of fuel system STCs will be necessarily cognizant of all non-fuel system STCs that could involve the co-location of fuel quantity harnesses, nor how we would have access (proprietary data rights could be involved) to the level of detail necessary to conduct such an installation review.

3.2 PROPOSED OPERATING REQUIREMENTS

Smiths Industries is in agreement with these recommendations.

3.2.1 Applicability of proposed operating requirements

Unless costs are prohibitive for the smaller aircraft, the proposed SFAR should not be limited to aircraft with a certified passenger capacity of 30 or more and payload capacity of 7500 pounds or more. It is pretty safe to say that the fuel safety concerns expressed in this NPRM apply to the complete range of passenger capacity aircraft and it is difficult to rationalize why the safety level for 29 passengers should be less than for 30 passengers.

3.2.2 Compliance

Whether 18 months is a sufficient period of time to implement any additional maintenance & inspection methods or to install any additional equipment necessary to comply with the SFAR is better addressed by those so affected, namely the aircraft operators.

3.3 PROPOSED CHANGES TO PART 25

While Smiths Industries feels it is absolutely necessary to address the prevention of ignition sources, unless flammable vapors can be totally eliminated from the tanks this is a less fruitful pursuit.

3.3.1 Fuel tank ignition source proposal

It is proposed that the FAA take a much more aggressive approach in the elimination of potential ignition sources from fuel tanks of new type designs for transport category aircraft. As documented in this NPRM, practically all fuel tank fire/explosion incidents and accidents are in some way related to the existence of electrical wiring, electrical energy or parts with rotating mechanical energy located within the fuel tanks. The most effective means to preclude this threat is to add a requirement to Part 25 that forbids the installation of such components within aircraft fuel tanks. This will not have the impact as may be first perceived since alternative methods are available, as with ejector pumps, mass flow meters and ultrasonic fuel measurement. Additional measures for future consideration are fiber optic, fluidic and pressure sensing devices. Any announcement of such a proposed change will no doubt lead to the development of additional innovative approaches. Forcing this change in technology will introduce both known and unforeseen problems, but none are expected to be insurmountable, or even close to the magnitude of problems associated with the potential or fuel tank fires and explosions.

3.3.2 Flammability Proposal

If the recommendation in 3.3.1 above is adapted, then the proposal for minimizing the development of flammable vapors in fuel tanks is of less significance. Nevertheless, the effort would still seem worthwhile in view of the potential for lightning and electrostatic ignition sources.

One rather common practice that can result in increased exposure to flammable vapors is directly discussed in the NPRM. This is the use of engine fuel-to-oil heat exchangers that in some designs return the heated fuel to the fuel tanks, generally in the form of motive flow for ejector pumps, including scavenge pumps. The hot motive flow for the scavenge pumps is retained within the fuel tank and leads to localized heating. This practice will need special emphasis if the proposal to minimize the formation of flammable vapors is pursued.

Another item that is only touched on briefly is the much greater exposure to flammable vapors when Jet B or JP-4 fuel is used. The general consensus seems to be that these fuels are no longer commonly used. However, it is believed that they still exist as approved alternate fuels for several transport aircraft. If any operators routinely use Jet B or JP-4 then their risk would be much greater than the risk for operators using Jet A. Should an effort be made to remove Jet B and JP-4 as approved alternate fuels for aircraft found to have significant risk for ignition sources?

3.3.3 Applicability of proposed change

Smiths Industries suggests that the necessary Instructions for Continued Airworthiness be identified in the STC top level drawing. Additionally, if such instructions apply to or affect flight procedures they should be so noted in the flight manual supplement. If such instructions apply to or affect maintenance procedures they should also be so noted in the maintenance manual supplement.

Smiths Industries strongly suggests that these requirements be extended to Part 23 aircraft and Part 27 rotorcraft as well.

3.4 FAA ADVISORY MATERIAL

It is the advisory material in the form of Advisory Circulars that provide the clearest intent of any regulation. There have been two ADs proposed in support of this SFAR.

3.4.1 AC No: 25.981-1X, Fuel Tank Ignition Source Prevention Guidelines

Smiths Industries has reviewed this document and is in general agreement with the proposed recommendations. In paragraph 6 (c) (5) (a) (2), Intrinsically Safe, there is a recommendation that energy introduced into any fuel tank be limited to 20 microjoules to be considered intrinsically safe. Designs that exceed the 20 microjoules threshold should not be considered unsafe as long as a suitable safety margin below the 200 microjoules limit exists. For example, a system with energy storage of 60 microjoules still has a safety margin better than 3 X the 200 microjoules limit

It is suggested that a similar recommendation to limit current to 10 milliamperes be added, consistent with paragraph 6 (b) (2) (a) (2), Filament Heating Energy Limit.

In paragraph (6) (c) (5) (f) (1) (bb), Establishment of a Safe Temperature Margin, the text should state "the lowest expected <u>auto-ignition</u> temperature of the fuel".

3.4.2 AC No: 25.981-2X, Fuel Tank Flammability Minimization

This Advisory Circular is most pertinent to the design of the aircraft fuel tank system and placement of airplane heat sources. This is an area that Smiths Industries does not have experience in, and therefore has no comments.

3.5 FUTURE REGULATORY ACTIONS

Smiths Industries believes that elimination of fuel tank flammability is technically feasible for new airplane designs, and encourages the FAA to pursue this objective.

4 COMMENTS ON PROPOSED SFAR

Smiths Industries is in general agreement with the recommendations of the proposed SFAR. It is strongly recommended that these requirements be extended to Part 23 aircraft and Part 27 rotorcraft.

5 SMITHS PROPOSED SOLUTIONS

Smiths Industries has expended significant resources in development of the Transient Suppression Unit, which will meet the requirements of this proposed rule for existing aircraft. Smiths Industries is also the leader in development of ultrasonic fuel gauging systems such as used on the Boeing 777 airplane. The ultrasonic fuel quantity system offers the opportunity to achieve higher accuracy performance while providing the aforementioned safety benefits. At this point in time capacitance systems with TSUs can not achieve the accuracy performance of ultrasonic systems. Smiths Industries is also developing the next generation optical based fuel gauging systems. A brief description of each of these systems follows.

5.1 RETROFIT OF EXISTING AIRPLANE FQIS SYSTEMS

5.1.1 AC Transient Suppression Unit

Aircraft that have the Smiths Industries 2300 series fuel gauge can have a Transient Suppression Units (TSU) installed to prevent transient and fault energy from entering the fuel tanks. The TSU limits the amount of energy storage within the FQIS m-tank components to 20 µJ and the current through any FQIS in-tank fault to 10 mA RMS.

5.1.1.1 AC Fuel Quantity Indication System (FQIS)

The 2300 series Fuel Quantity Indication System (FQIS) uses an array of capacitive probes and a capacitive compensator in a bridge configuration to determine the amount of fuel in the tank. The probes and compensator are driven with a 7400 Hz sinusoid voltage of from 0 to 10 volts peak amplitude. The two drive signals are 180° out of phase and their relative amplitudes adjusted by the fuel gauging system until the return signal is at null.

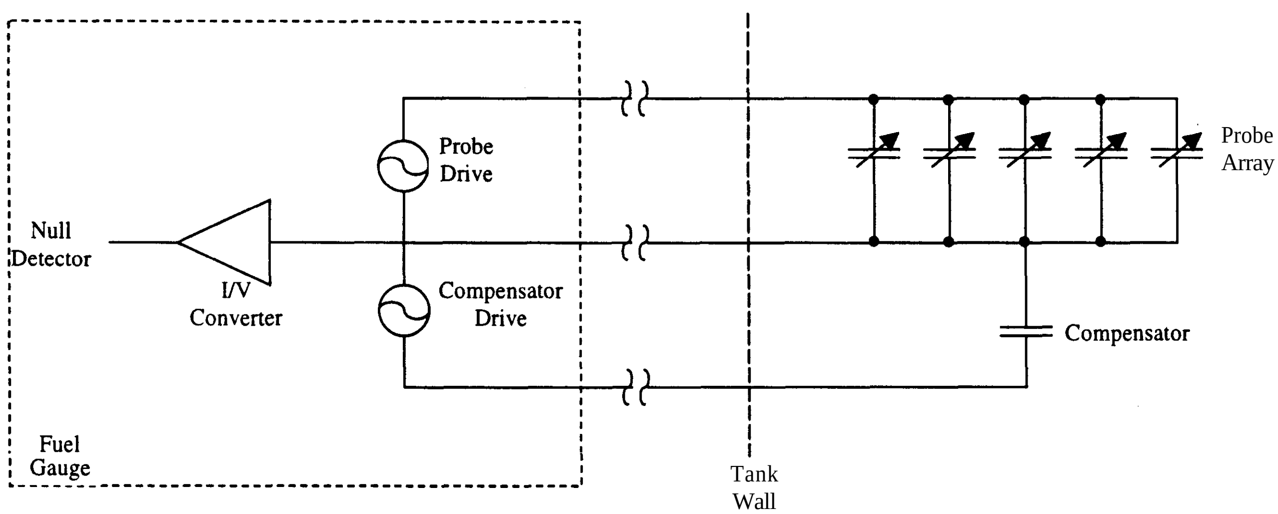

Figure 5-1 2300 FQIS Functional Diagram

The ratio of the drive signals is inversely proportional to the ratio of the probe to compensator capacitance. From this ratio, the quantity of fuel within the tank is determined.

5.1.1.2 Threats

Several threats to the fuel tanks exist as a result of the FQIS system. Outside of the fuel tank, the FQIS harness is subject to EMI and lightning transients, which could propagate into the tank. The FQIS harness is also routed with other wiring, which may include power buses. Thus, insulation failure within the harness could result in a fault between the FQIS wiring and a power bus.

Within the fuel tank, energy is stored within the probe and compensator capacitances and also within the stray capacitance that exists between each line and the airframe and between the individual lines. Debris within the tank could include conductive matter that can bridge the gaps within the probes or from a probe to the airframe.

Various combinations of these conditions could result in a hazardous situation. For example, if conductive debris is partially bridging the gap from a probe to the airframe and a lightning transient occurs, the voltage level could rise on the probe line until a discharge occurs across the gap. If the voltage level is sufficiently high, sufficient energy may be present to ignite the fuel-air mixture within the tank. Or, if debris completely bridges the gap and a wiring fault occurs, current flow through the debris could result in heating of the debris to the auto-ignition temperature of the fuel-air mixture.

5.1.1.3 TSU Operation

The Transient Suppression Unit (TSU) is placed in line with the fuel gauge wiring, as close to the tank wall as possible. The TSU clamps the voltage that enters the tank so that the maximum energy storage within the in-tank capacitances is below 20 µJ. This 20 µJ level is below the worst case ignition energy that could occur within the fuel tank. The TSU also limits the RMS current that can flow into the tank. By limiting the current, the amount of heating is also limited, so that the worst case auto-ignition temperature is not reached.

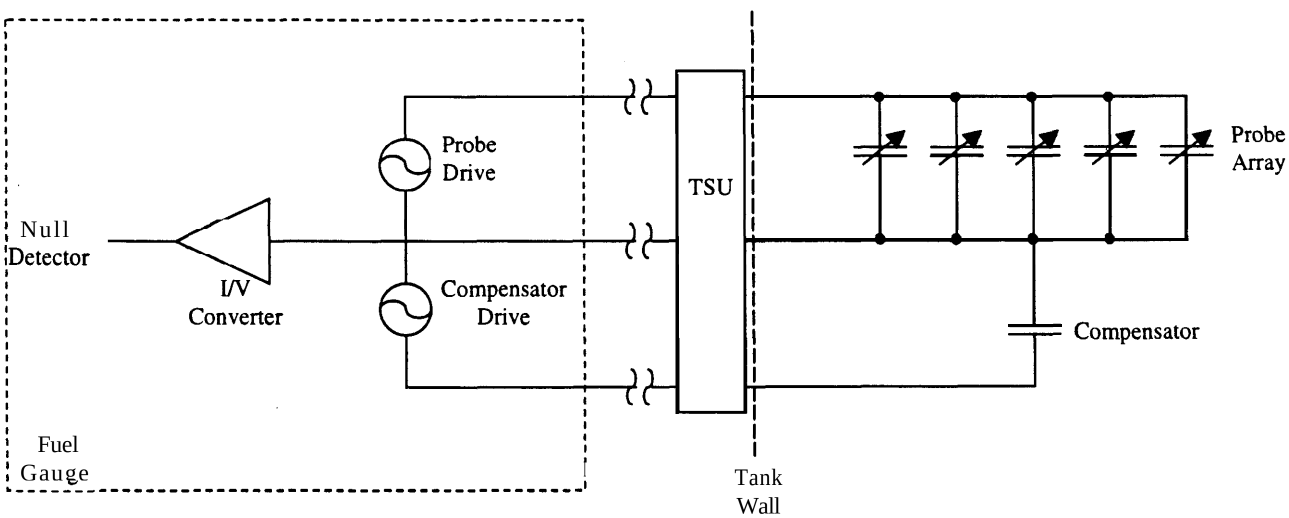

Figure 5-2 2300 FQIS with TSU

A simplified TSU circuit is shown below. Each fuel gauging line has a similar circuit. It consists of a voltage clamp that uses a Transient Voltage Suppression (TVS) device to clamp the voltage and a series resistor to limit the current under fault conditions. A fuse is also included to open the circuit in the event of a long term fault.

Following the voltage clamp is a current limiting impedance. For the Hi-Z return line, a simple resistor is used. For the Lo-Z lines a series LC circuit is used that is tuned to the gauge drive frequency. This is necessary to keep the total impedance on the Lo-Z lines small, so that fuel gauge operation is not affected. To provide current limiting at the gauge drive frequency, a saturating inductor is used in the series LC circuit.

After the current limiting impedance is a low pass filter consisting of a capacitor to ground and a ferrite bead. This is to prevent high frequency EMI signals from entering the tank.

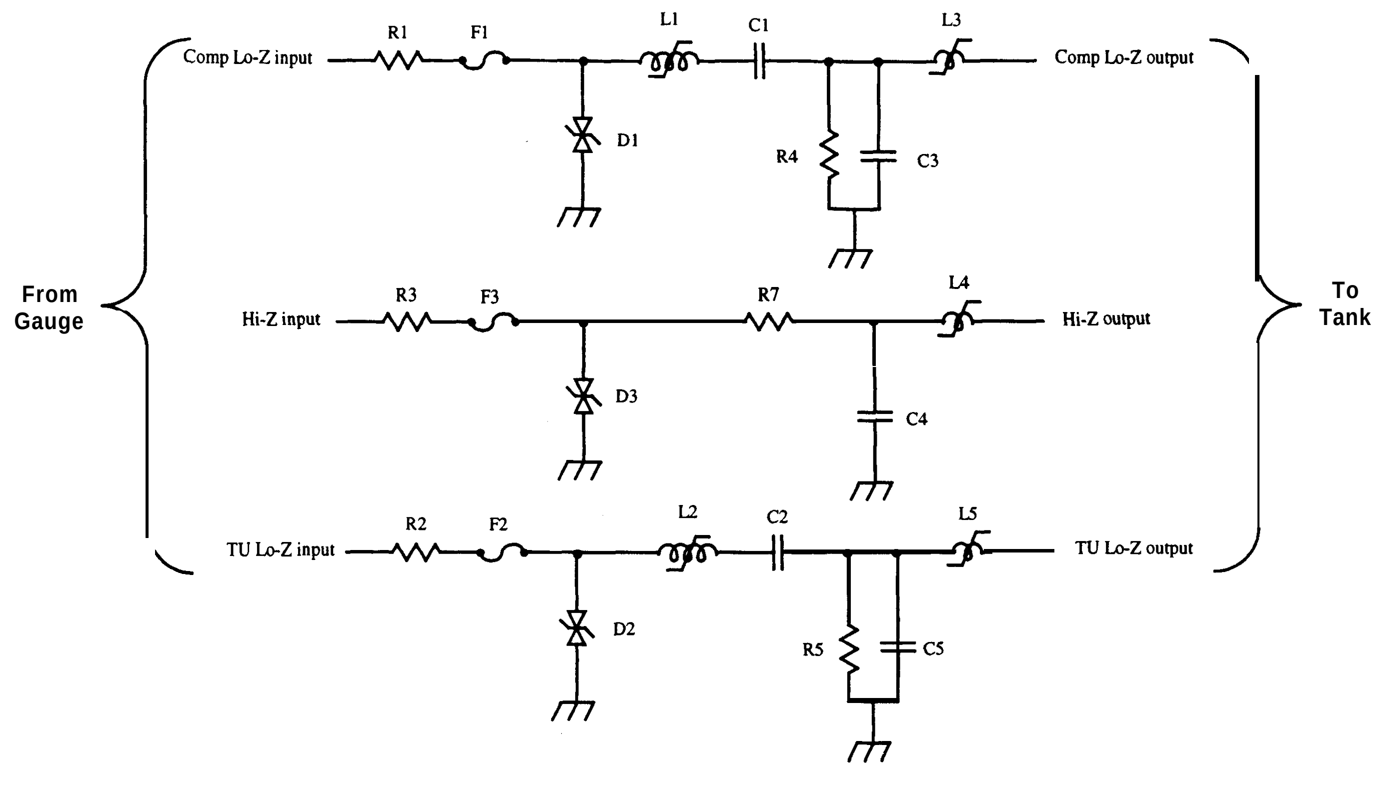

Figure 5-3 Simplified TSU Schematic

5.1.1.4 TSU Mechanical Packaging

The mechanical packaging of the TSU is dependent upon the aircraft it is to be used on. For the Boeing 747 aircraft, the TSU package is made to be sandwiched between the FQIS tank wall connector and the out-tank harness connector. This places the TSU right on the tank wall, resulting in no exposed wiring that is not protected by the TSU.

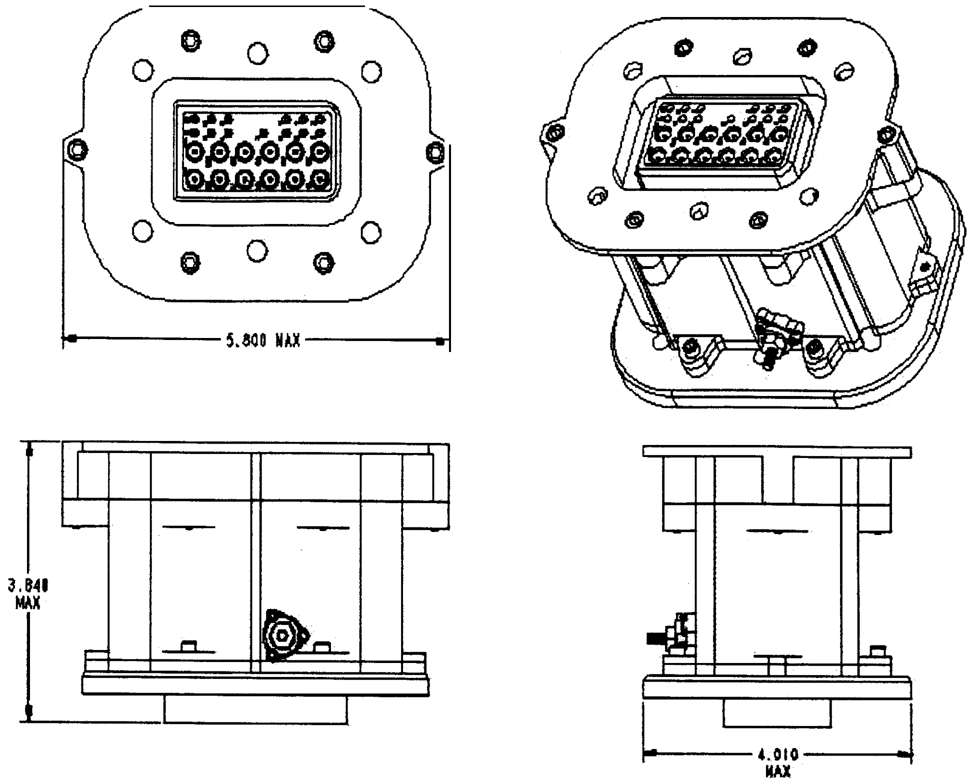

Figure 5-4 747 Rectangular TSU (four wing tanks)

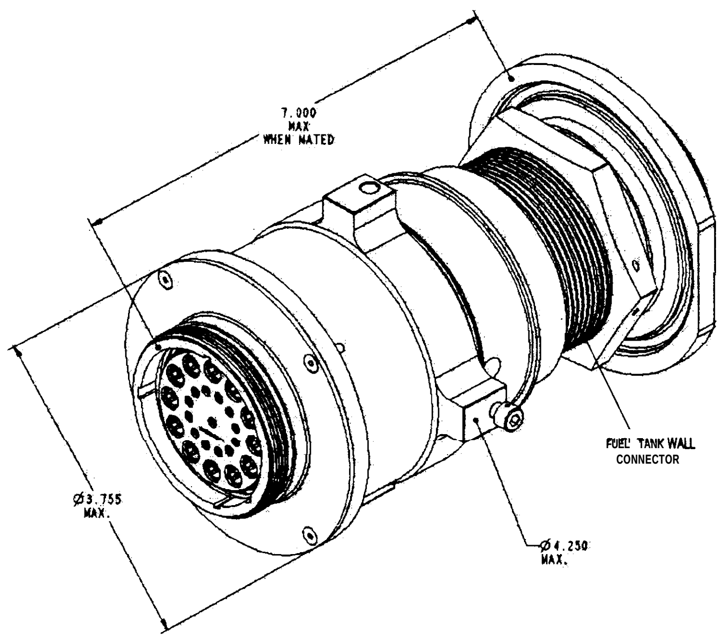

Figure 5-5 747 Circular TSU (four wing tanks)

The Boeing 737 application has the TSU circuitry housed in a box that is mounted adjacent to the tank wall connector. A remotely mounted TSU is required because the tank wall connector on the 737 is not large enough to support a TSU. The out-tank harness is connected to the TSU and a short cable connects the TSU to the tank wall connector. The cable between the TSU and the tank wall connector includes an overbraid to shield it from EMI signals. This cable is of short length and is routed so that it is not near any other cables that could pose a threat.

TSU packaging for other aircraft will be developed as the need arises. In many cases the approach used for the Boeing 737 can be adapted simply by creating a new cable to connect the TSU to the tank wall.

5.1.1.5 TSU Reliability

The TSU has a relatively simple circuit that uses only passive components. As a result, it is very reliable. A single tank TSU has a calculated Mean Time Between Failure (MTBF) of over 140,000 hrs when using the reliability models of MIL-HDBK-217F. A TSU for the four tanks of a 747 wing has a reliability of over 50,000 hrs.

Even though the TSU has a high overall reliability, the requirement that the occurrence of an ignition source be extremely improbable results in the need for redundancy within portions of the TSU. A Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) were performed for the TSU and the FQIS, respectively, in order to identify those area where redundancy was needed. As a result, redundant TVS devices, EMI filter capacitors and capacitors in the series LC circuits are used. This results in a FQIS that meets the requirements of the SFAR by installation of the TSU alone and not additional shielding and segregation of wire harnesses.

5.1.1.6 TSU Maintenance Practices

There are several redundant components within the TSU that could fail without being detected during normal operation on the aircraft. Failure of any one of these components would not affect fuel gauge operation and the TSU would continue to protect the fuel tank. But, a subsequent component failure could degrade the protective function of the TSU. For this reason, the TSU should be tested every 25,000 hrs to verify that it has no failed components. This testing requires that the TSU be removed from the aircraft and shop tested to verify that the redundant TVS devices and redundant EMI filter capacitors are still functioning. The testing is non-intrusive and does not require disassembly of the TSU. By performing precise measurements on the TSU pins, it can be determined whether any of the redundant components have failed.

5.1.1.7 TSU Advantages

Installation of a TSU provides a simple way of bringing the FQIS into compliance with the SFAR. Installation does not involve extensive down time of the aircraft and does not require replacement of harnesses or opening of the fuel tanks. There is little risk that damage will occur to other aircraft systems during the installation and the cost is relatively low.

5.1.1.8 Retro-fit Applications

The TSU can be used with any aircraft with a Smiths Industries 2300 series FQIS currently certified via Supplemental Type Certificate (STC) or Service Bulletin on the following aircraft:

- Boeing 727
- Boeing 737
- Boeing 747
- McDonnell Douglas DC-8
- McDonnell Douglas DC-9
- McDonnell Douglas DC-10
- Fokker F-28

The 2300 series FQIS is suitable for use on any aircraft that uses bussed AC tank probes that are contoured to provide a linear relationship between probe capacitance and fuel level.

5.1.2 DC Fuel Quantity Indicating System

Being a supplier of DC capacitance fuel quantity systems we are also developing transient suppression units for these systems.

The Airbus A320, CH-47 and C-141 systems are typical of Smiths Industries DC gauging technology.

5.1.3 Ultrasonic Fuel Quantity System

5.1.3.1 Brief System Description

The ultrasonic fuel probes, mounted within the aircraft fuel tanks, comprise a hollow tube body, attached to a transducer housing. A ceramic transducer crystal is potted in a housing at the bottom of the probe. This crystal emits an acoustic wave, which is transmitted through the fuel to the fuel surface. The reflection time of this acoustic wave is measured and forms the basis for the computation of the fuel depth and hence the volume and mass.

The probe body is not part of the electrical system, and is also bonded to the airframe structure to ensure discharge of any static electrical charges that might occur on the probe body.

A unique twisted pair of wires supplies the transducer, in each of the probes in a given tank. Inside the tank these twisted pairs are routed individually to each of the probes. External to the tank and connecting the tank wall connector to the Fuel Computer, the twisted pairs from all of the probes in a given tank are grouped together, enclosed within two layers of copper braid and then covered with an overall layer of insulation. The thickness of the insulation is nominally 1.45mm in the unpressurized zones, and nominally 0.5mm in the pressurized zones. The copper braids are bonded to aircraft structure. This insulation and shielding provides continuous, full 360-degree coverage for the wires from the tank wall connector to the Fuel Computer with no breakout pigtails.

The system is designed around the internationally accepted 'Intrinsic Safety' standards of IEC Standard 79-11 or equivalent.

5.1.3.2 Design Standards, System Analysis and Test Data

A detailed analysis of the system and its components, including the in-tank probes and wires, external airframe wiring to the probes and the Fuel Computer confirmed that, under all single fault conditions, the energy and current levels were below the specification limits and not capable of producing a spark capable of igniting the fuel within the tank(s).

An extensive program of induced voltage tests, carried out on the total system, including Fuel Computer, harnesses and fuel probes, confirmed that the design requirements had been met. These tests included Radio Frequency and Audio Frequency conducted and radiated susceptibility, power line and bus transients and spikes, and lightning induced (including multiple burst) transient susceptibility. In all cases the specifications relative to safety were met.

The design of the system is such that there is no electrical power within the fuel tanks other than the twisted pair wiring to the transducers. Each probe is connected via its own wiring to the Fuel Computer, thus eliminating paralleled and grouped wiring within the fuel tank(s), as used in capacitance systems.

The safety of the system is not compromised by debris, conductive or non-conductive, within the probes since they are electrically inactive.

The build-up of static charge on the in-tank probes cannot occur since these are conductive and are bonded to the airframe structure.

All non-metallic/insulating materials within the tank have been chosen and tested to ensure long term resistance to the effects of fuel over the specified temperature range.

An extensive 'BITE' capability ensures that faults in any part of the system are detected and indicated. This includes undetected faults which may not directly affect system performance, e.g. open-circuit fuel probes.

5.1.3.3 In-Service Experience

The system is basic fit to the Boeing 777 aircraft and has seen in airline service since May 1995. No problems have been reported which relate to damage or deterioration of the electrical insulation of the probes or the wiring between the probes and the Fuel Computer, either in the tanks or the airframe.

5.1.3.4 Summary

5.1.3.4.1 Transients

The ultrasonic system design, which includes double braid screening over the grouped, twisted pair wiring from the fuel tanks to the Fuel Computer will eliminate the need for the addition of transient suppression and/or screening and separation of this wiring. This has been confirmed by the extensive test program referenced at Paragraph 5.1.3.2.

5.1.3.4.2 Short Circuit Effects

The 'Intrinsic Safety' standards applicable to the system ensure that no in-tank or twisted pair wiring faults can produce a spark capable of causing ignition.

The possibility of short-circuit faults to out-tank wiring is removed by the mechanical protection provided.

The BITE system on the UFQIS ensures that there are no undetected failures that could affect safety.

The system is electrically isolated from the fuel and is thus unaffected by debris in the tanks, (unlike a capacitance system).

The whole of the UFQIS system is also isolated from the aircraft ground.

5.1.3.4.3 Static

Since the probe body is electrically bonded to the structure, there is no possibility of the build-up of static charge.

5.1.3.4.4 Conclusions

The inherent safety of the Ultrasonic Fuel Quantity Indication System (UFQIS), as described, is not compromised by normal or abnormal electrical transients from sources within or external to the aircraft. Thus, no additional transient devices are needed and the possibility of additional system failures and hazards and maintenance problems from such devices is avoided.

The electrical and mechanical design is such that the only potentially critical part of the system within the tank is the wiring to the probes. The basic 'Intrinsically Safe' design of the system, ensures that there are no single failures within the system which can result in sufficient energy being present within the tank such as to produce a spark capable of causing fuel ignition.

Double failures involving a short circuit to the probe wiring are eliminated by the mechanical and electrical design of the wire bundles between the tanks and the Fuel Computers. Also there are no undetected faults in the system which can lead to an unsafe condition following such a second failure.

5.2 Optical Level Sensor

The optical level sensor, shown in Figure 5-6 is an off-the-shelf, flight proven device which uses the difference in refractive index between air and fuel to detect the presence of fuel. The device can operate as either a high or low fuel level sensor. The proposed level sensor uses opt-electronic technology in sensing the presence or absence of fuel. The interface to the optical level sensor is via an intrinsically safe barrier (low power, low current) and offers a safer level sensing solution than the 28VDC float switch technology in wide application today. The level sensor is an integral unit that is mounted internally to the tank independent of the probes.

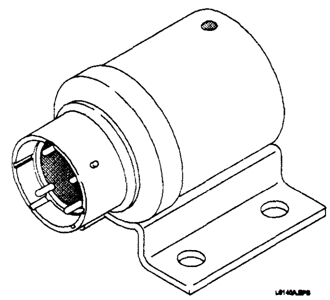

Figure 5-6 Optical Level Sensor

5.3 NEXT GENERATION FQIS SYSTEMS

The ultimate objective for Smiths Industries is the development of a fuel quantity indicating system that requires no electrical ‘devices or introduction of electrical energy into the tank. Numerous studies into the technologies (most notably optics and pressure sensing) that satisfy this objective led us to believe that while technically feasible, such systems are too costly by today’s standards (approximately 3 times those of current systems). As a company, Smiths Industries is continuously monitoring the technology advances that would lower the cost barrier and hasten the introduction of these promising techniques, and is actively involved in development of these technologies. Smiths Industries would be willing to share additional details with the FAA and other regulatory agencies on a proprietary information basis.

5.3.1 Control by light

While the complete elimination of electrical energy from the tank may not be immediately achievable, there are measures available today that greatly enhances the safety of fuel quantity systems. One system that Smiths Industries is actively pursuing in conjunction with Raytheon Commercial Electronics, eliminates external electrical wires from the fuel tank wall connector. Dubbed the “Gauge By Light” *(or* “Optical Fuel *Quantity”?)* system, this innovative system uses a fiber optic interface to derive all the necessary FQIS power and communications interfaces from light energy. The use of non-conductive fiber totally isolates the in tank sensors from external ignition sources.

A simplified block diagram of the Gauge by Light system is illustrated in Figure 5-7. All out tank connections to the tank wall interface unit are via non-conductive fiber optics. The tank wall interface unit contains a light-to-power converter section that derives all of the electrical energy necessary to measure the fuel probes and to communicate with the external airframe system(s) from the light source located in the remote fuel processor. The tank wall interface circuit contains all of the provisions to limit the probe excitation current to 10mA and the energy to 20 microjoules. The system uses a light source that is automatically de-energized in the event of a harness break or open connector. The intrinsic safety provisions in the tank wall interface unit comply with the requirements of UL – 913 and are far more secure when compared to those of many of today’s systems where the intrinsic safety barrier is remote such as flight deck located indicators or EE rack mounted processors. In these systems, one must rely on harness separation and overbraiding for protection against HIRF & lightning induced or hot cable short threats. These provisions can be compromised by mis-installation or in service maintenance and operation.

Locating the probe interface circuits at the natural intrinsic safety barrier formed by the fuel tank wall and isolating these circuits from all external ignition threats via nonconductive interfaces advances the safety of fuel quantity systems to a level far greater than that achieved with wire separation. Furthermore the intrinsic safety of systems that rely on harness provisions require periodic inspections and maintenance steps that are prone to human error.

The optical system we have initially developed is compatible with industry standard capacitance probes but the system could be adapted to ultrasonic probes as well as to fiber optic sensors themselves.

Smiths Industries and Raytheon Commercial Electronics are prepared to install the optical fuel quantity system on an aircraft to demonstrate the advantages of our innovations. We would be pleased to make a formal presentation and proposal to any party interested in such an evaluation.

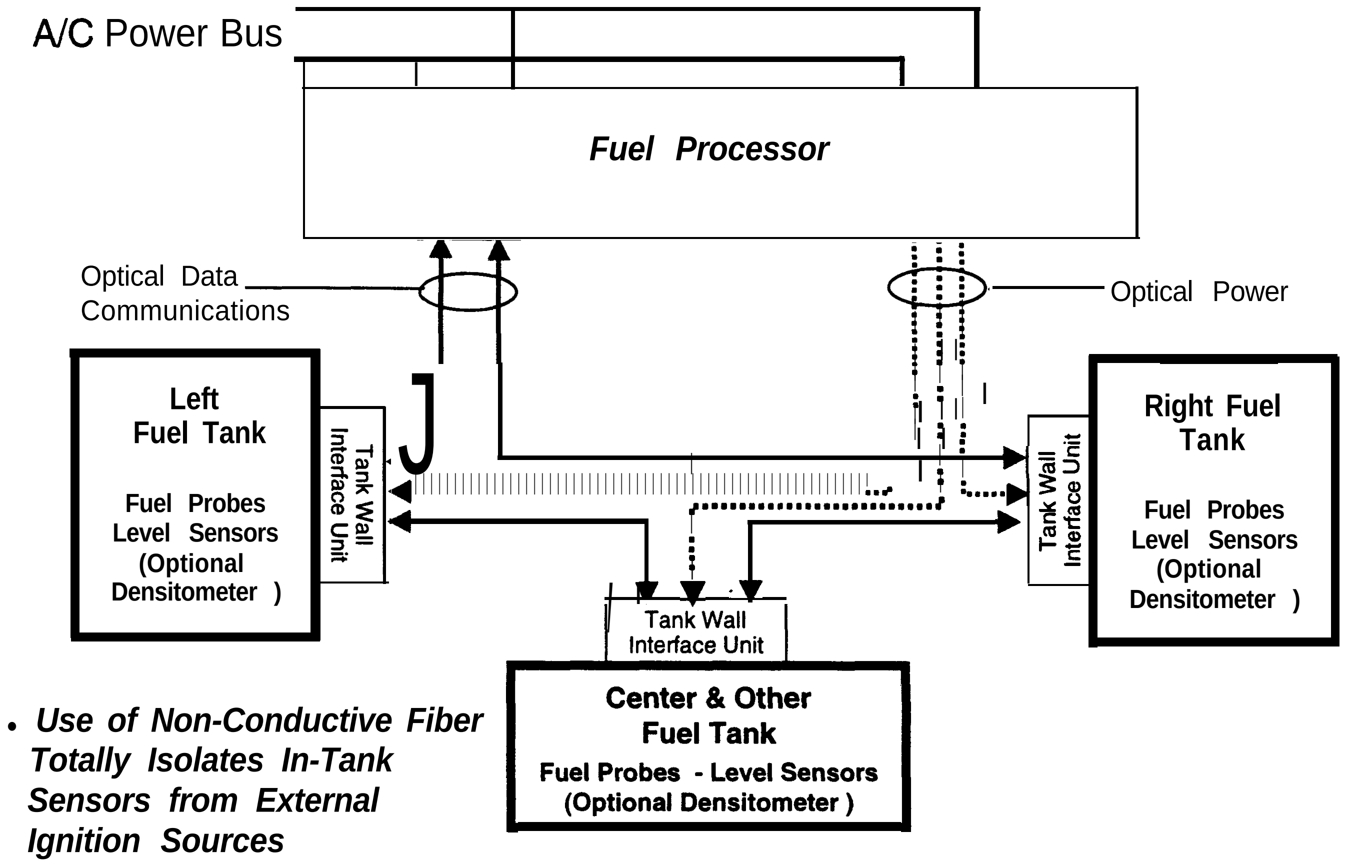

Figure 5-7 Gauge by Light System

5.4 FUTURE FQIS SYSTEMS

5.4.1 Fiberoptic FQIS

Smiths Industries has filed a Patent application for a optical fuel quantity measurement system that completely eliminates electrical wire harnesses from within the fuel tanks and from the fuel tanks to the electronics bay. This system uses the properties of light to excite capacitance type probes in the fuel tank, and to transmit optically the readings of each probe. The inherent safety advantages of this approach are obvious. This system is currently under development at Smiths Industries Research and Development facility in the United Kingdom.

5.4.2 Other

Smiths Industries is also pursuing other technologies for future fuel measurement systems. The use of pressure sensors to measure fuel height is under investigation, as is the placement of ultrasonic sensors on the outside of fuel tanks.

5.5 PUMP & VALVE POWER

Several issues with pumps in particular have been identified as a result of all the inspections made of Boeing 737 and 747 aircraft. Arcing of pump power leads within conduits was identified, for example. There are currently no means for detecting the presence of such conditions, and standard circuit breakers have been shown to be ineffective in such situations. Smiths Industries has a program to address these issues, as described below.

5.5.1 Arc fault protection

Consideration should be given to monitoring any pump and valve power lines that enter the tank to determine whether arcing is occurring. Arcing is serious because there is a voltage drop of some tens of volts across the arc, so when a high current flows, a large amount of power is dissipated in the arc. Very high temperatures are reached, and the arc can cause damage to wiring and conduit and act as an ignition source. But because arc current only flows for a portion of the voltage cycle, traditional thermal circuit breakers have low sensitivity to arc faults.

SI is in the process of developing Arc Fault Detection (AFD) technology. Analysis of arc fault waveforms and the current waveforms, which can occur in normal operation, has shown that the current drawn by an arc fault has particular “signature” characteristics. The detector therefore looks for these characteristic differences to differentiate between arc currents and normal inrush currents and other transient effects. In the event of an arc being detected, power is disconnected from the faulty circuit. This could determine instances where arcing to pump housings and wiring to conduit are occurring, as described in the notice. Detection of an arc situation, with consequent removal of power within some tens of milliseconds, would preclude significant damage to conduit or housings.

This type of ‘health monitoring’ could also be beneficial in detecting deterioration in pump performance due to wear or debris, and alerting the need for maintenance, long before the pump became an ignition source. A similar technique to that used for arc fault detection could be used to detect malfunctioning pumps before the pumps overheated and became a fire risk. For example, if the worst-case inrush current taken by a fault-free pump to run up to full speed is known, excessive magnitude or slow decay of inrush current could be taken as an indication that the pump motor was faulty or the pump was being fouled. For this type of health monitoring, the detector circuit could have two levels of detection, the lower for an anomaly warning and the higher for a trip command. The anomaly warning would be fed out for display on a health page, for action at next maintenance opportunity, the trip command would disconnect the power to the faulty circuit.

6 CONCLUSIONS/RECOMMENDATIONS

Smiths Industries supports the issuance of the proposed SFAR. Several recommendations have been made that should enhance the document, and make it more workable within the aircraft community. The FAA is to be applauded for taking a stand on these issues, which will result in added safety for those who travel in airplanes.

Smiths Industries does believe that these requirements would also benefit Part 23 aircraft as well as Part 27 rotorcraft, and the FAA is encouraged to extend these requirements to these categories.

Smiths Industries has several solutions to these requirements for existing aircraft, and is working on next generation fuel gauging systems that will further enhance safety.

From a fuel system supplier's point of view, Smiths Industries views these proposed requirements as desirable, and economically achievable.